High Speed Devices and Circuits

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Lecture - 20

MESFET Operation and I-V Characteristics

We have been discussing the various aspects related to Schottky barrier. We have seen what are the factors which affect the barrier height, what are the factors which affect the built-in potential, ideal, non-ideal characteristics, I-V characteristics, all those we have discussed. Now, we are ready to use it in a 3-terminal device. The 3-terminal device which is very popular with 3-5 compounds particularly gallium arsenide, gallium nitrite and all those substrates where the wide bandgap is there; there it becomes more and more difficult to make pn junctions they use metal semiconductor MESFET - Metal Semiconductor Field Effect Transistor. ME stands for metal; S for semiconductor; field effect transistor. We will discuss how it operates, what the operation of this device is and how do the I-V characteristics look like. In fact, this will be similar or almost same as that of the junction field effect transistor.

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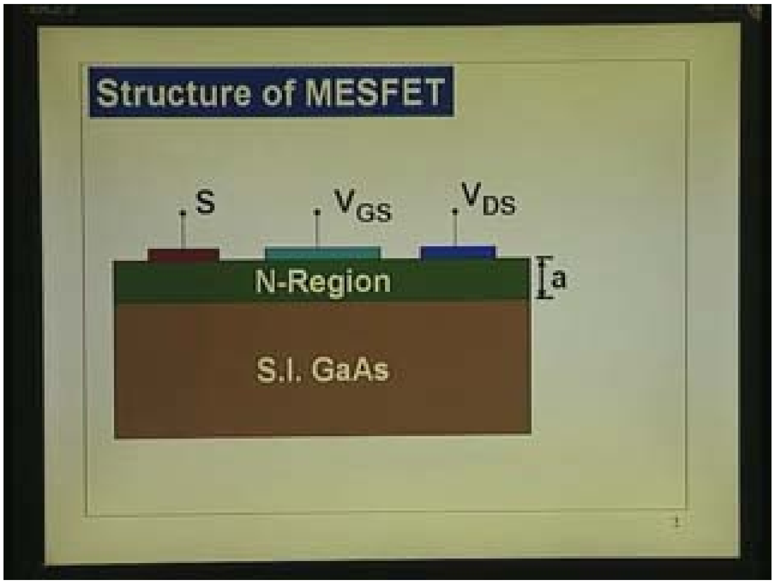

Structure of MESFET

If you see, this is the structure of the metals semiconductor field effect transistor. Now, using the gallium arsenide as the substrate because that is very popular with gallium arsenide integrated circuits. Integrated circuits have been realized with this approach. Semi-insulating gallium arsenide on that you have an n region and this n region can be either realized by epitaxial technique or by implanting on to this semi insulating substrate. There is a layer which is doped with usually silicon or sulphur that is the donors. Now you have got here this red or this region as the source that is the ohmic contact and the drain that is also ohmic contact. When you say it is ohmic contact you understand what it is now. It is gold germanium alloyed on to that contact n type region that makes the ohmic contact. Straight away evaporate gold germanium alloy at 400 degree centigrade for about a minute, you get the ohmic contact. We will have occasion to get more into the technology details later. This portion is actually the metal semiconductor contact which actually should be a rectifying contact because you need to control the region below this. Ohmic contact does not have any effect below that it only allows the current to flow in either direction with minimum voltage drop; whereas, you need a rectifying contact which means below that is metal contact there will be a depletion layer and the extent of depletion layer will depend upon what is the voltage that is applied to this.

If this metal semiconductor that is if you apply a plus voltage with respect to the source ohmic contacts that is a forward bias junction. If I apply reverse bias that is V_{GS} is negative that will be a reverse bias junction. I am just using the term $V_{GS.}$ V_{GS} actually is positive if it is forward bias. Please understand this terminology: gate to source potential is positive if it is forward biased; gate to source potential is negative the applied voltage is negative with respect to source if it is reversed biased. Nothing is applied when you shorten this there will be a built in potential across the channel metal semiconductor junction. All that you have now is an insulating layer which does not do anything it is a mechanical support an n type layer with two contacts at this point and at this point from here to there. We can say that, the contact is current connection begins from this end current injection from this end. This is a source; this is the drain. Usual term for MOS. MOSFET source is the source of electrons; drain is drain for electrons current flow will be in this direction if I apply voltage between the drain and the source. Now, let us take a look at this operation.

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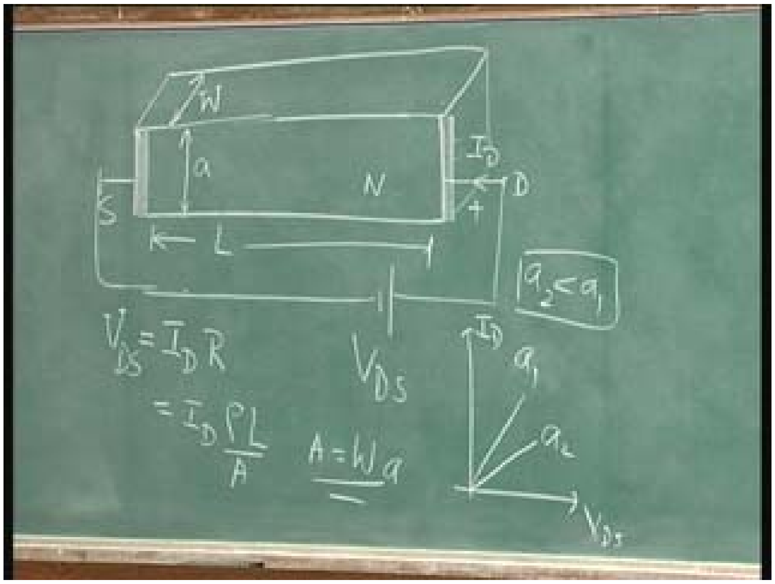

I will just draw this particular diagram there suppose I have a bar of semiconductor n type. I put a contact here: this is the source; this is the drain. Now, if the voltages are low when I apply V_{DS}, this is n type, there will be a current flow like this. I can call it as I_D. There will be a current flow from.., let me draw little bit that side I_D, and I am applying V_{DS} plus there minus there. This is like a bar of semiconductor. Voltage drop V_{DS} will be equal to I_D into the resistance, simple, ohms law. V_{DS} will be I_D into R, where, R will be resistance of this region. If this depth is W if that depth this is the cross section. W is the depth perpendicular to the board if the depth is W then R is actually equal to this, I can put it as, let me just rewrite it over here. I_D into R equal to V_{DS} which is actually equal to I_D into rho L divided by area that is all we are telling. rho is the resistance resistivity; L is the length between the two contacts, and A is the area of cross section. Area of cross section if this is a, area will be actually equal to W into a; where W is actually the depth. In fact, if I call this as the channel length of length L, if I call this as L total length L, L is the length between the two and W is the depth. Remove it from here put it as N that is W and of course here you will have this coming like that. It is a bar of semiconductor. If I have this bar of semiconductor like that it does not serve any purpose for us. Finally, what we want is I must be able to vary this current using another terminal. Simple way is if I can vary this current this will have a characteristics like this, V_{DS} versus I_D will be like that. The slope of that is the resistance. You know this device is simple to understand. All that you need to know is ohms law and apply it properly that is all what we need to know. That is the characteristics. I want to change this current supposing I want to reduce the current. If, I can reduce the thickness of this layer, let us say you have a way of electronically etching that layer remove this layer the thickness a if can be reduced by some height this field get another slope which is like this: a_1 a_2 and (Refer Slide Time: 10:39) a_2 will be less than a_1. This is actually the understanding that you have got when you take area reduction. Now, the same can be achieved. You must be able to achieve it electronically the area of cross section that is the thickness of that channel you must be able to reduce that is done by applying the voltage to gate.

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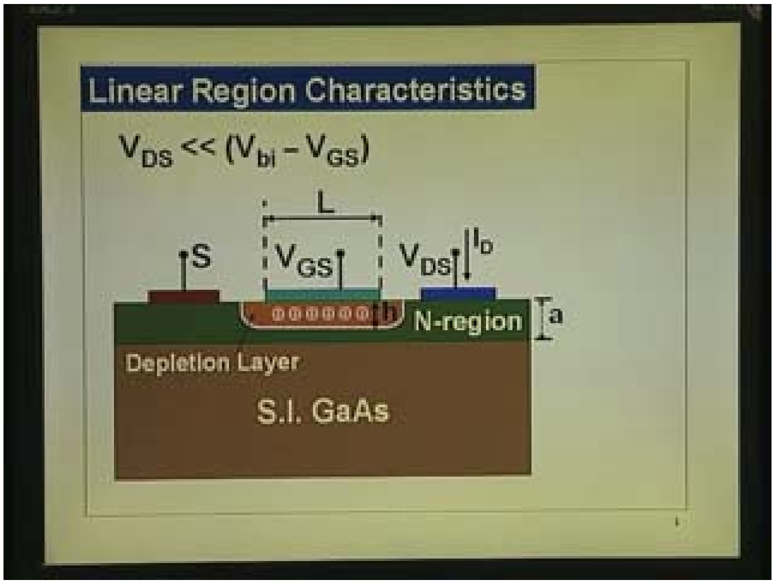

Linear Region Characteristics

$V_{DS} << (V_{bi} - V_{GS})$

What I have shown here is the same structure whatever we put on the board except instead of putting the contact right here at this edge I have not shown the gate. I have shown this length L this is the L and here if I go this is the L. We are telling that you do not put the contact there physically. You have put it slightly away from that because you do not want to sort this gate to this row source we get. There must be a separation between the two regions.

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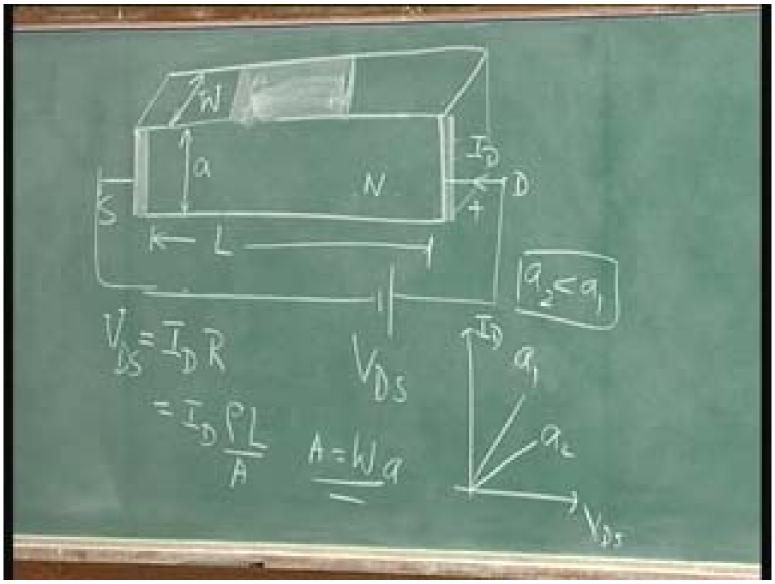

What you have will be a contact, we have put here like this that is a contact on the top that you have put and we are in the first analysis where, we neglect the drop across that neglect a drop across that. What is the meaning of that? It means as if the contact is put here all that we are saying is whatever V_{DS} you are applying is practically appearing across that. You can do that by putting n plus 1 type here. We can have n plus region from here to here then as if shifting this contact to this portion. In the physical we are doing is Shockley analysis. Shockley first gave in 1950 way back. That was given where, the contact is even though it is there you neglect the drop here you neglect the drop there. Now, due to this metal semiconductor contact, what do you have below that? See this height thickness of this n layer I put it as a similar to what we have put there and the depth of that into this plane we have taken it as W. In all the analysis you do that and this n region we call it as a channel because, the region has been in which the current flows channel length is L, from that end the channel length is L same terminology that is used in the case of MOSFET channel depth is or width is W and channel thickness is a. It is this you are controlling by applying voltage to the gate and source. Supposing, I sort the gate to the source 0 voltage between gate and source the channel thickness is a minus this depletion layer width. What I have put here is h, h is the depletion layer width and the depletion layer width is related to the built in potential.

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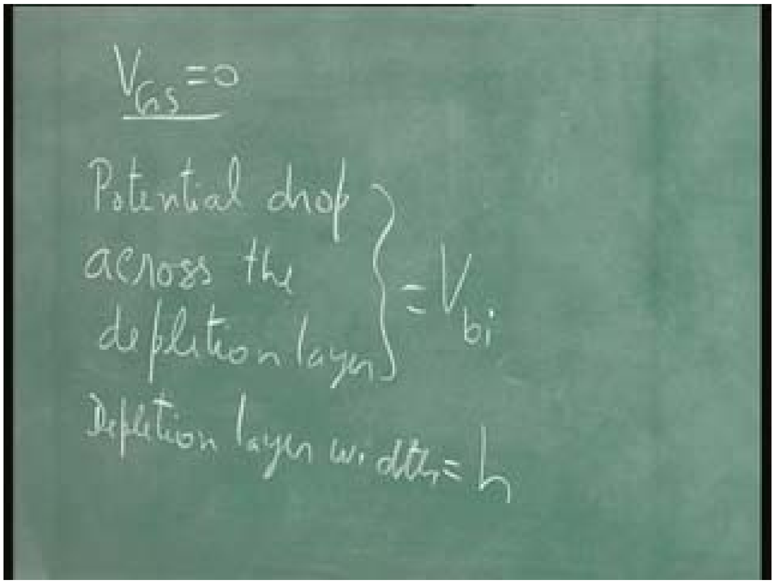

$V_{GS}=0$

Potential drop across the depletion layer $\Big\} = V_{bi}$

Depletion layer width = h

Let us go into this discussion little bit more carefully the depletion layer width we are considering V_{GS} equal to 0 then potential drop across the depletion layer is equal to V_{bi}. Depletion layer width is h, let us remove that V_{bi} there is a depletion layer width.

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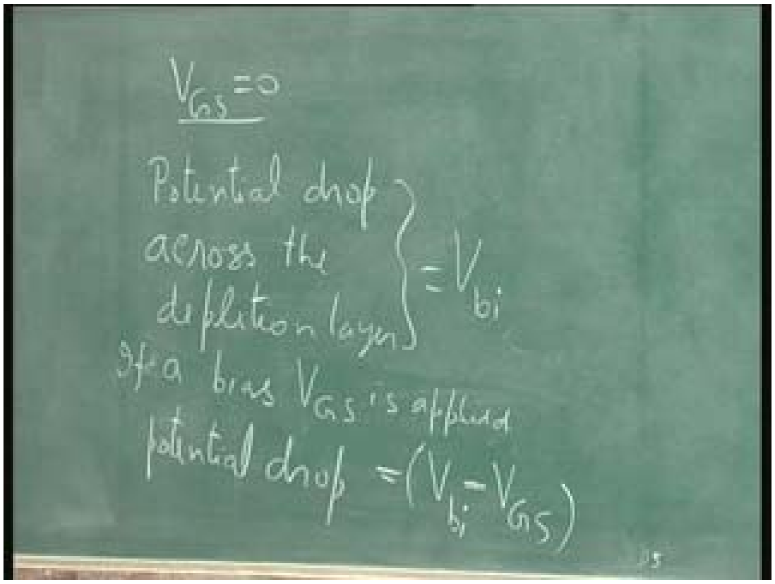

$V_{GS}=0$

Potential drop across the depletion layer $\Big\} = V_{bi}$

If a bias V_{GS} is applied potential drop $= (V_{bi} - V_{GS})$

Now, if a bias V_{GS} is applied then voltage or the potential drop is equal to this I would like you to watch carefully, we can put numbers on to that in analysis what we will put it as V_{bi} minus V_{GS}. Look if V_{GS} is positive it is forward biased the total potential will be V_{bi} minus V_{GS} minus that V forward bias if V_{GS} is minus Vr that is reverse bias it will be V_{bi} plus V_i. You do not have to say anything all that you have to do is put V_{GS} put plus 0.5 or minus 0.5. If I put plus 0.5 this is V_{bi} minus minus 0.5 that is forward bias. If it is minus 0.5 volts reverse bias it is V_{bi} plus 0.5 that is all what we to do please remember there is no confusion. Consistently, we will use V_{GS} as gate to source voltage and polarity is shown with gate positive the applied voltage is reversed, we put it as negative. In equations we will always put like this. Now let us take a look at the turn.

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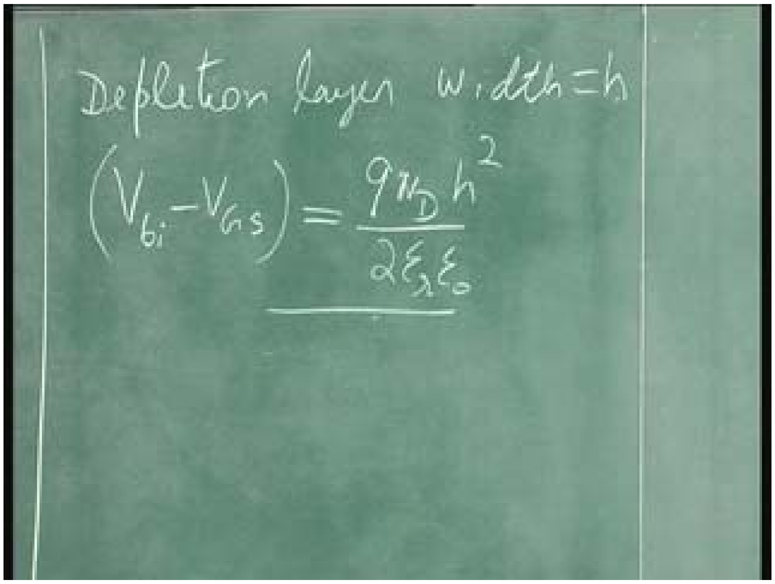

Depletion layer width = h

$$\left(V_{bi} - V_{GS}\right) = \frac{q N_D h^2}{2 \varepsilon_r \varepsilon_0}$$

I will go back to depletion layer width. Depletion layer width is h that is related to the potential across the depletion layer. Therefore, V_{bi} minus V_{GS} is the total potential. You do not have to worry whether it is reverse biased or positive biased all that you have to do is give a proper sign to V_{GS}. V_{GS} is positive it is the forward biased V_{GS} is negative it acts on to that. I am repeating that q N_D h square divided by 2 into epsilon$_r$ into epsilon$_0$ that is the depletion approximation. Please remember we will be using only this equation in the analysis completely. If you want to find the channel thickness a, originally it was a, now it has been reduced by some amount h. You go back to this slide here, see original channel thickness is a. It is reduced by this depletion layer width because out of this pores thickness a, this entire thickness h is occupied by the depletion layer no mobile carriers are there. Conduction takes place only through this layer. It is as if you have removed that layer. As far as the drain source region is concerned or the channel is concerned it is as if we etched out that portion. But, physically it is there. You have removed the electrons. This is the insulating layer virtually and the conduction takes place through this layer. The channel thickness now is a minus h that is the width and h depends upon that quantity. Now, you can see if V_{GS} is negative this increases that h increases h will be actually be equal to I think I have got those equations that slight probably we will see h can be related from this equation. All that we have to do is find out the voltage and the depletion layer height. You do that, subtract it from the channel thickness a you get the area of cross section for a current flow. Then, use that equation V_{DS} equals to I_D into R where, R is a variable quantity R you are varying by applying gate voltage that is all it is as simple as that. So all the symbols are clear the I_D is the drain current which will flow through this channel and notice that depletion layer width is uniform everywhere, implying a potential drop across the depletion layer is same here, here, here or at least there is not much difference between the potential drop across the depletion layer at this source end and at the drain end. That means a drop in this direction is negligible that is what is written here. The drain to source in fact when we say drain to source at V_{DS} what we are considering is from this edge to this edge. That is active region when you write all the equations, we are writing equation when we say V_{DS} it is just across the channel length. We are not considering the drops beyond that point that we can add as I_r drop because this portion this portion thickness is not changed.

Just now we said it is a constant resistance that we can add up later if you want to. Other hand if you bring in this contact closer and closer to this the drop may look smaller. This aspect we will see later. We will see how to bring it closer together at what impact it has on the I-V characteristics that has to be seen in the practical device. These are the problems that people faced with them when making the MESFET in gallium arsenide initially because in the case of MOSFET you have self aligned structures. Whether you can get self aligned structures in this device our analysis really holds good for self aligned structures in the sense n plus coming closer to this point. So, we imagine that this contact is close to this point with that understanding and also with understanding that initially what we take is V_{DS} dropped from here to here is very small compared to V_{bi}

minus V_{GS}. V_{bi} minus V_{GS} is drop (Refer Slide Time: 21:39) here; drop from this point to this point this. You want to operate this device with V_{GS} positive because that may start conducting. We will see that later. In other word what we telling is if V_{GS} is 0 channel thickness is maximum it is that is depletion layer width is minimum. As you keep on increasing the V_{GS} reverse bias negatively the depletion layer keeps on widening. Channel thickness becomes smaller and smaller resistance becomes more and more current is not current becomes smaller. With that let us see now, these symbols should be clear to you h a I_D V_{DS} etc and L is the channel length depth is W.

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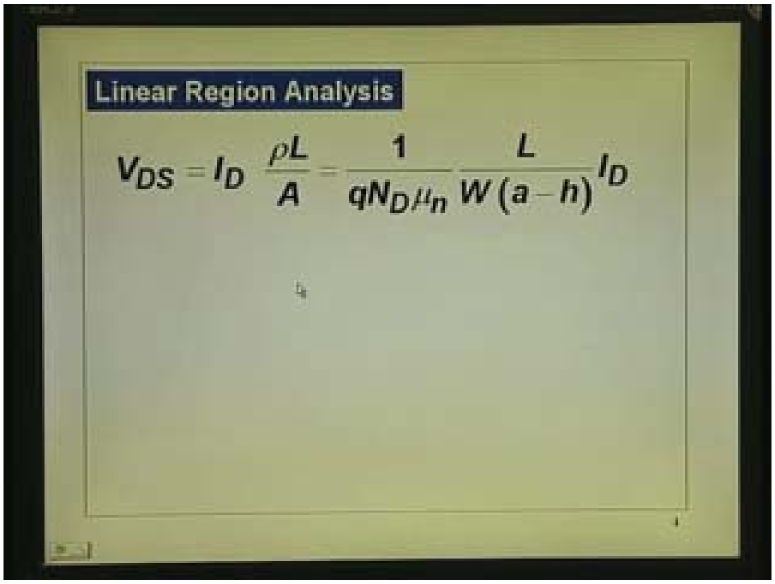

Linear Region Analysis

$$V_{DS} = I_D \frac{\rho L}{A} = \frac{1}{qN_D\mu_n}\frac{L}{W(a-h)}I_D$$

There we have rewritten that equation what I wrote initially V_{DS} now ohms law I say linear region because that is the region where V_{DS} is very small compared to that. When we say linear I_D V_D characteristic will be linear. If you satisfy this condition this whole region from here to here is a fixed resistor of height a minus h, h is constant right through. V_{DS} is equal to I_D into rho L by a L is the channel length rho is the resistance of the n layer a is the area of cross section. Now, if we see substitute it is much simpler compared to MOSFET in fact, even circuit engineers enjoy writing this equation because it is all that is there. Rho is 1 by q N_D mu_n that is rho the first term, this is sigma q N_D mu_n is sigma 1 by sigma is rho and area of cross section depth is this height which is equal to a minus h a minus h is the channel thickness now depth is W, W into a minus h is area of cross section L is the length V_{DS} is equal to I_D into rho into L by A.

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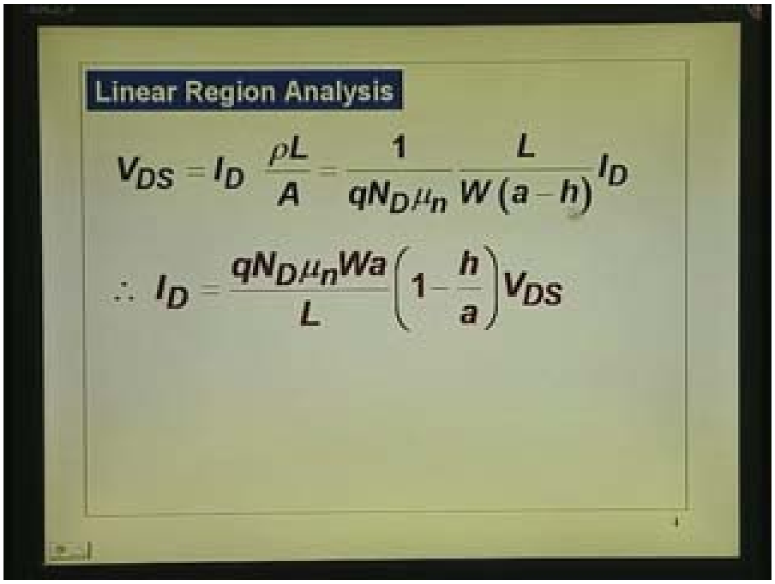

Linear Region Analysis

$$V_{DS} = I_D \frac{\rho L}{A} = \frac{1}{qN_D\mu_n}\frac{L}{W(a-h)}I_D$$

$$\therefore\ I_D = \frac{qN_D\mu_n Wa}{L}\left(1-\frac{h}{a}\right)V_{DS}$$

Now, I put I_D is equal to V_{DS} into this whole thing goes up to numerator I put it in terms of I_D now. I_D is equal to q N_D mu_n W taken on that side I pull this a out and within bracket you get 1 minus h by a. I have just rewritten all that we have done, in fact we have difficulty I will put it back on the board.

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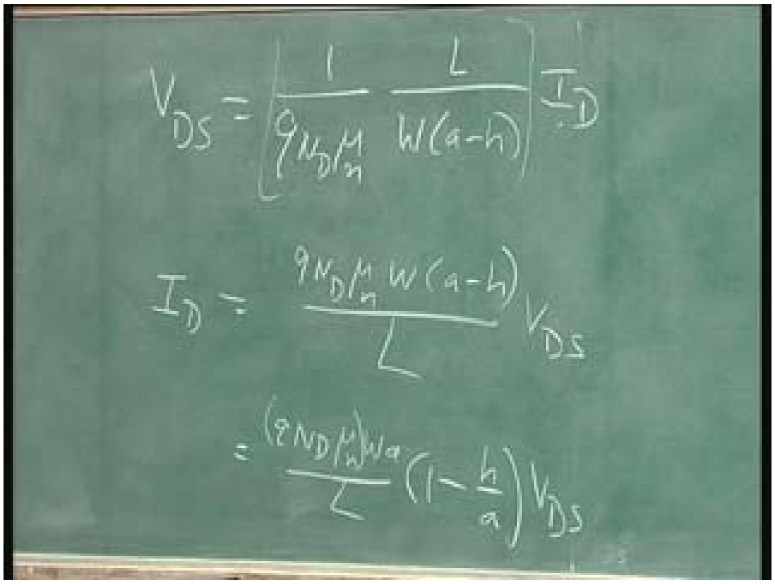

$$V_{DS} = \left[\frac{1}{q N_D \mu_n} \frac{L}{W(a-h)}\right] I_D$$

$$I_D = \frac{q N_D \mu_n W(a-h)}{L} V_{DS}$$

$$= \frac{(q N_D \mu_n) W a}{L}\left(1 - \frac{h}{a}\right) V_{DS}$$

V_{DS} is 1 by q N_D mu_n that is rho 1 by that is rho into L divided by area. W into a minus h into I_D this is whole thing is R. Therefore, I_D is actually equal to q N_D mu_n into W into a minus h divided by L into V_{DS}. I pulled out this a and you get q N_D mu_n W into a divided by L into 1 minus h by a into V_{DS} this term this quantity is nothing but 1 by rho sigma, sigma into area by L.

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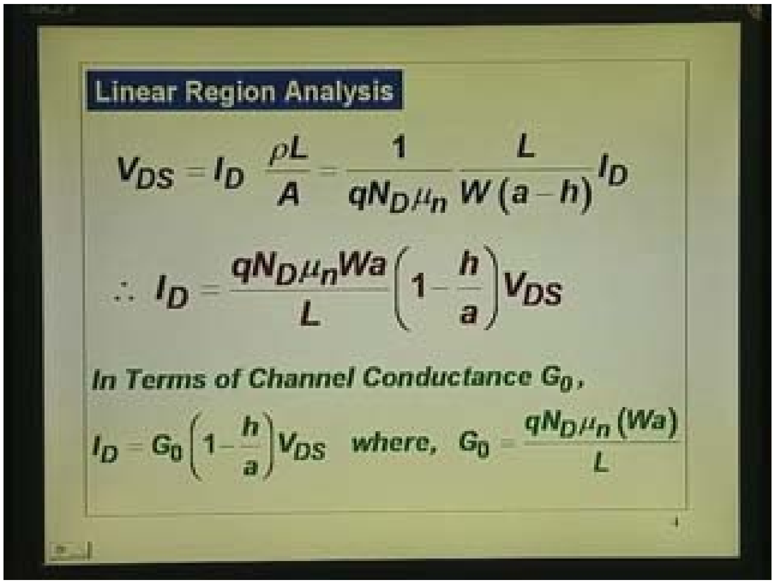

Linear Region Analysis

$$V_{DS} = I_D \frac{\rho L}{A} = \frac{1}{q N_D \mu_n} \frac{L}{W(a-h)} I_D$$

$$\therefore I_D = \frac{q N_D \mu_n W a}{L}\left(1 - \frac{h}{a}\right) V_{DS}$$

In Terms of Channel Conductance G_0,

$I_D = G_0\left(1 - \frac{h}{a}\right) V_{DS}$ where, $G_0 = \frac{q N_D \mu_n (Wa)}{L}$

I put that whole term see this particular term as sigma into area of the full channel. If there is no depletion layer the channel thickness is a and depth is W. W into a is cross section of that entire resistor. Let me just go back and show you. If there is no depletion (Refer Slide Time: 26:52) layer, that is a and that is L depth is W rho into L divide by W into a that is resistance channel resistance and I put it as channel conductance 1 by that sigma into area by L that is G_0 G_0 is that quantity. I am writing that because, it works out easy to write that one alone. Instead of writing all this right through if there is no depletion layer channel resistance would have been 1 by G_0. But, it is never that much it is always higher than that because it is not a it is always less than a because of depletion layer. Once you have got this you should be able to write what is h and a. For that, we define one particular term. You have got the current relationship between I_D and V_{DS} here all these are constants here. This is a constant, a is a constant once we decide the thickness of epilayer h it is a constant for a given V_{GS}. Whole thing is a constant for a given $V_{GS.}$ You will get a characteristics I_D proportional to V_{DS} for a given V_{GS} array and I can get similar characteristics formed by varying V_{GS}. Now write a instead of writing it a, it is become easier to define a term called pinch of voltage. Now, let us just go into one or two things I want to write here this is the equation that we have got.

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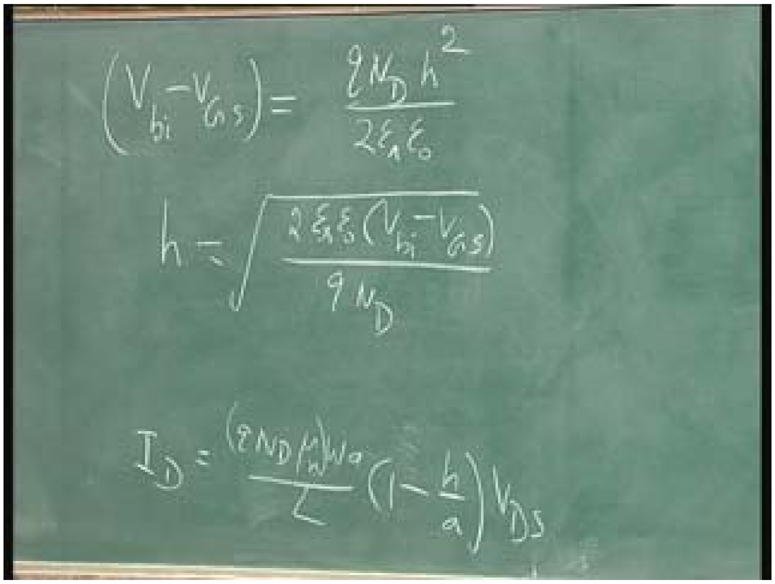

$$(V_{bi}-V_{GS}) = \frac{q N_D h^2}{2\varepsilon_r \varepsilon_0}$$

$$h = \sqrt{\frac{2\varepsilon_r \varepsilon_0 (V_{bi}-V_{GS})}{q N_D}}$$

$$I_D = \frac{(q N_D \mu_n) W a}{L}\left(1-\frac{h}{a}\right) V_{DS}$$

This is the equation you have got, we have seen that h is equal to we have seen V_{bi} minus V_{GS} is the total potential across the depletion layer which actually is equal to I think you should retain this term correct. h is actually equal to root of twice epsilon_r epsilon_0 V_{bi} minus V_{GS} divided by this is complete depletion approximation you have got. This is the h term. Now you define a term for pinch of voltage I want h by a ratio here h is related to the V related to V_{GS}. If I increase V_{GS} reverse bias more and more that term goes on increasing.

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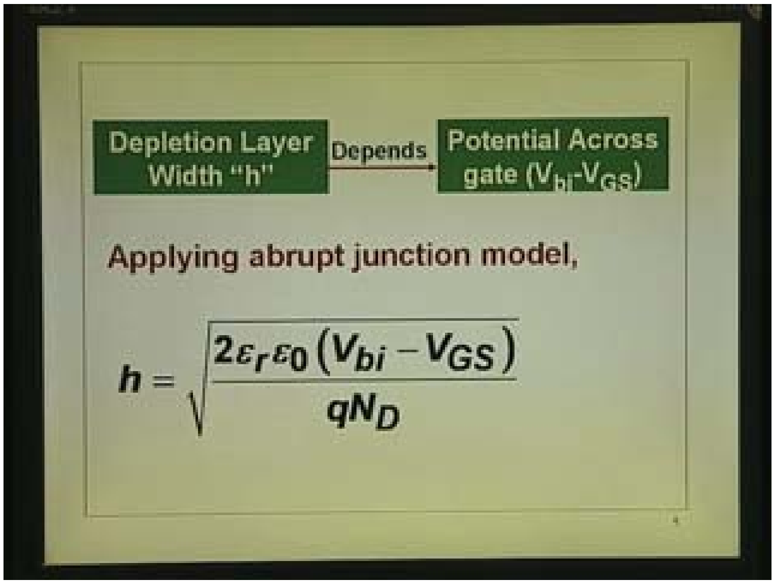

Depletion Layer Width "h" Depends **Potential Across gate (V_{bi}-V_{GS})**

Applying abrupt junction model,

$$h = \sqrt{\frac{2\varepsilon_r \varepsilon_0 (V_{bi} - V_{GS})}{qN_D}}$$

Now I define a term pinch of voltage. Let us see depletion layer width h depends on the potential across the gate V_{bi} minus V_{GS} applying abrupt junction model that is what you have written there twice epsilon_r epsilon_0 V_{bi} minus V_{GS} by q N_D. Always remember this equation again and again I will be using it here. Best thing to remember is h is proportional to square root of V_{bi} minus V_{GS}.

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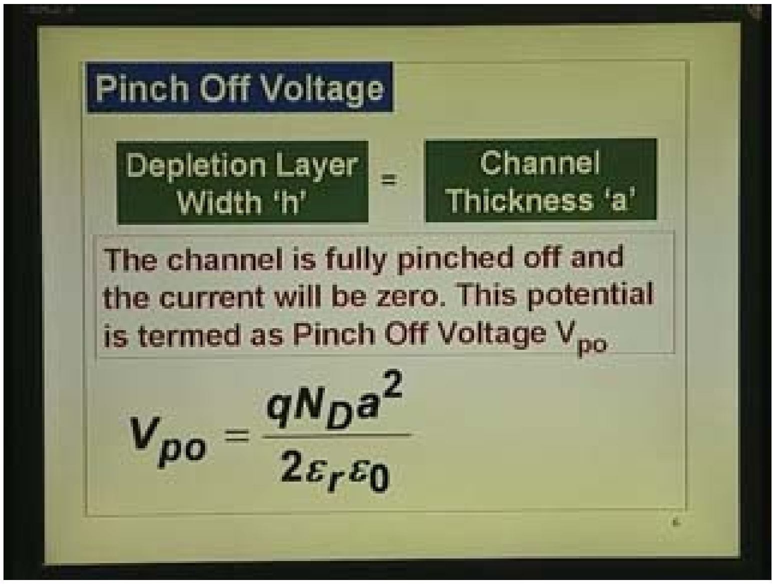

Pinch Off Voltage

Depletion Layer Width 'h' = Channel Thickness 'a'

The channel is fully pinched off and the current will be zero. This potential is termed as Pinch Off Voltage V_{po}

$$V_{po} = \frac{qN_D a^2}{2\varepsilon_r \varepsilon_0}$$

Reason is now we define a term called pinch of voltage where, depletion layer h becomes equal to a. We defined a pinch of voltage as the potential drop across the depletion layer required to make h equal to a. The channel is fully pinched off completely depleted and the current will be 0, if the depletion layer completely goes all over totally then the current will be 0. This potential is termed as pinch off voltage V_{p0}. I will go back to this once to see the thing you are finding out how much should be the potential drop across the junction. The depletion layer completely comes all the way up to this insulating layer. It is closing down entirely there are no carriers present anywhere in that region between source and drain complete layer is depleted. What is the potential across (not the applied voltage) this depletion layer so that the channel is completely depleted? That we call as pinch of voltage. This is related to h. I am replacing this by a and defining the total potential instead of V_{bi} minus V_{GS} I have got V_{p0}, it is not the applied voltage it will include the built applied voltage also width it may be depleted at 0 bias also depending upon thickness. V_{p0} is h is replaced by a. The potential drop required across the junction or schottky junction to make the depletion layer equal to a. That means, we can write instead of h is proportional to V_{bi} minus V_{GS} a is proportional to square root of V_{p0}.

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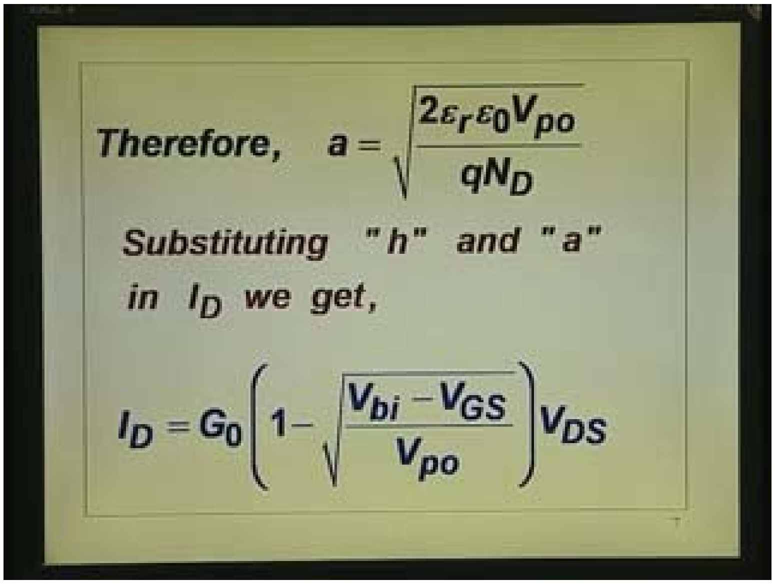

Therefore, $a = \sqrt{\dfrac{2\varepsilon_r \varepsilon_0 V_{po}}{qN_D}}$

Substituting "h" and "a" in I_D we get,

$$I_D = G_0\left(1 - \sqrt{\frac{V_{bi} - V_{GS}}{V_{po}}}\right)V_{DS}$$

That is the same equation when you wrote h here when we wrote h the V_{p0} was equal to is replaced by V_{bi} minus V_{GS}. Therefore, substituting h and a in I_D we got the term G_0 into 1 minus h by a V_{DS}. I substitute for h and a. What is h divide by a? h is this.

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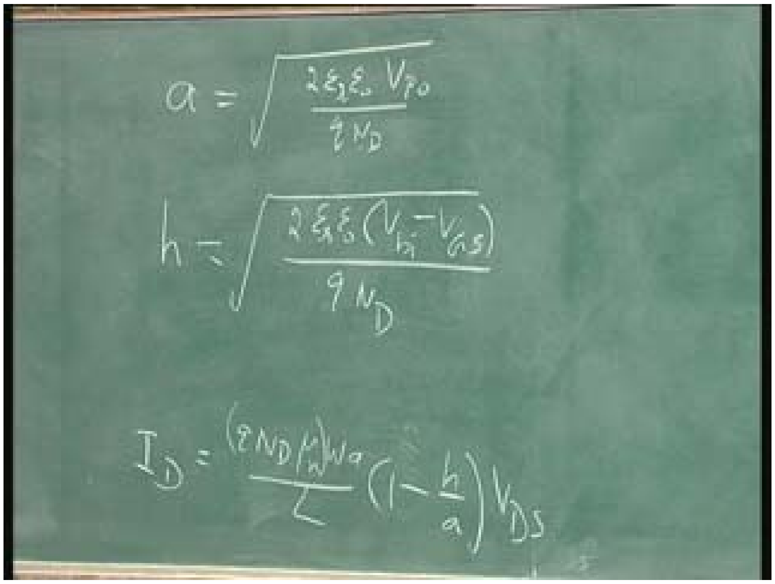

$$a = \sqrt{\frac{2\varepsilon_r \varepsilon_0 V_{p0}}{q N_D}}$$

$$h = \sqrt{\frac{2\varepsilon_r \varepsilon_0 (V_{bi} - V_{GS})}{q N_D}}$$

$$I_D = \frac{(q N_D \mu_n) W a}{L}\left(1 - \frac{h}{a}\right) V_{DS}$$

Now, a is actually equal to square root of twice epsilon_r epsilon_0 into V_{p0} by q N_D. h divide by a is actually equal to square root of the potential all these things cancelled h divide by a is square root of V_{bi} minus V_{GS} divide by V_{p0} that is it. All that we have done is substituted h and a. G_0 into 1 minus h by a into V_{DS} is the I-V characteristics that is that. Now, we can see clearly why we wrote V_{p0} because V_{p0} is fixed for a device whose thickness and doping is fixed. When you fix the device doping and thickness are fixed. So, V_{p0} is fixed. That is why write in terms of V_{p0} pinch of voltage and this come handy by analyzing at the device characteristics later. Now, you can see here this is linear characteristic for a given V_{GS} I_D and V_{DS} are linear for a given V_{GS} go back to this V_{GS} equal to 0 it is 1 minus V_{bi} by V_{p0} square root of into V_{DS}. If I increase the V_{GS} the reverse bias, this V_{bi} plus that reverse bias quantity.

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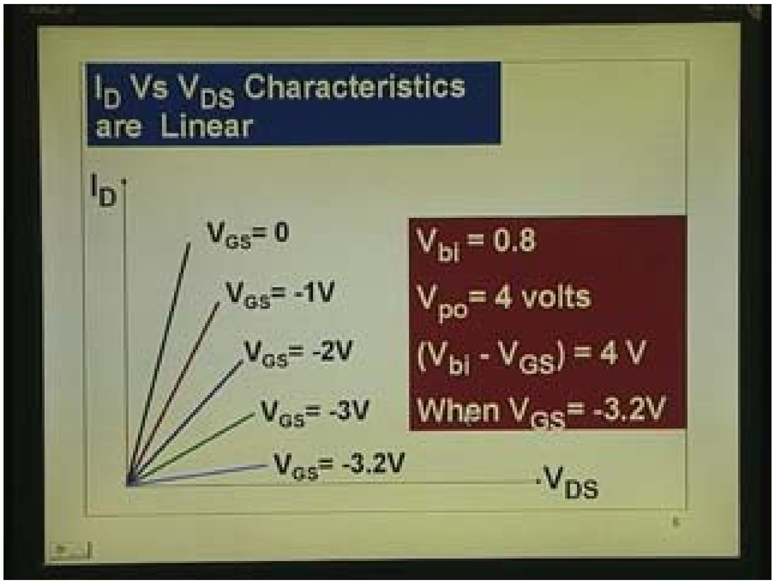

I_D Vs V_{DS} Characteristics are Linear

$V_{bi} = 0.8$

$V_{po} = 4$ volts

$(V_{bi} - V_{GS}) = 4$ V

When $V_{GS} = -3.2$V

So, V_{GS} equal to 0. I am taking it as a typical case where V_{bi} is 0.8volts, volts is missing there 0.8 volts V_{p0} is 4 volts. V_{p0} is 4 volts so if V_{bi} is 0.8 volts when V_{GS} equal to minus 3.2 volts reverse bias the total quantity will be equal to this is 0.8 volts V_{bi}. This is minus 3.2 so 0.8 minus minus 3.2 that is 4 volts. When the V_{bi} minus V_{GS} equal to 4 volts you have got a potential drop across the channel equal to V_{p0} the current at that point in fact is very small. I just (36:31) small current virtually everything is gone down there may be small leakage current will be there. I did not show it as 0 but virtually it will be 0. This will be almost flat this is when V_{GS} is reverse biased so much that the channel is depleted fully all the way. So, from 0 we keep on increasing reverse bias minus 1 minus 2 minus 2 minus 3.2 you are able to shut off the transistor completely. The device conduction is made 0 that is the u, using this equation you can really find the slope of this. The circuit engineers use this behavior in many places in circuit application such as linear circuits. I am sure some of the people who teach that would have been talking about that one of the very popular application is in a Weinbridge oscillator just leaving this because as electrical engineer you would like to take a look at that also. A very good example is when you make a Weinbridge oscillator it is amplifier of gain three with RC, RC combination as in the feedback circuit; let me draw that quickly.

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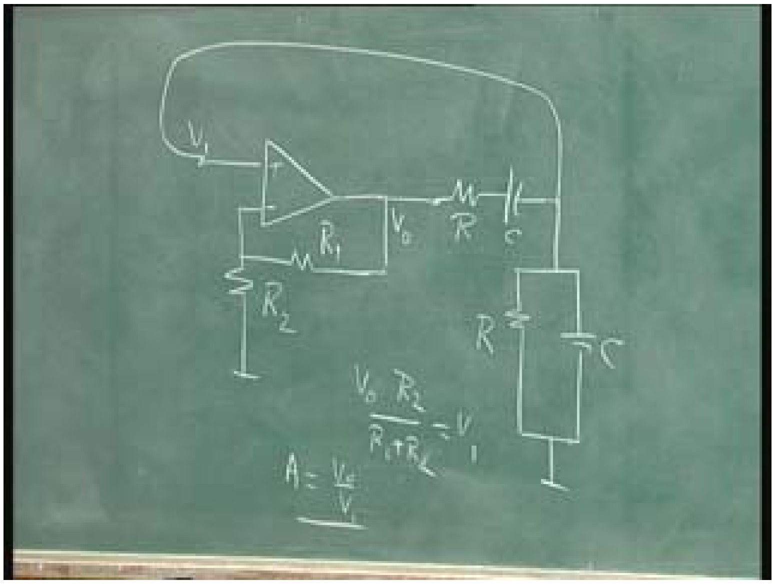

As a recapitulation for the memory see if you have a simple amplifier circuit we will put an (38:14) amp R_1 R_2 the ratio is such that, see for example this will V_0 this is V in V_1. V_0 into R_2 divide by R_1 plus R_2 that is the voltage here that is equal to that, that is equal to V. You have got A is equal to V_0 by V_1 which is nothing but 1 plus R_1 plus by R_2. 1 plus R_1 by R_2 I think you are being tired of this things probably 1 plus R_1 by R_2 is 3 that means R_1 by R_2 is equal to you make this 2 compared to that that is 3. Then what do you have in Weinbridge. For sake of completeness I am drawing capacitor here R C and then I am drawing for the purpose and connect this to feedback that is Weinbridge oscillator RC RC everything is here. Frequency of oscillation equal to 1 by 2 pi RC. But, what will be the amplitude of this? We have no control; you put down the power supply to this

(39:55) amp it will turn on. We will see that amplitude goes on building up. What is the limiting factor here? Finally it is limited by its non-linearities. The non-linearities when it is set in, it is less than supply voltage it will make up some value. Now, let us say 3 volts at the output peak what will you do is you must have this resistor adjusted such that, only for that output voltage the gain becomes equal to 3.

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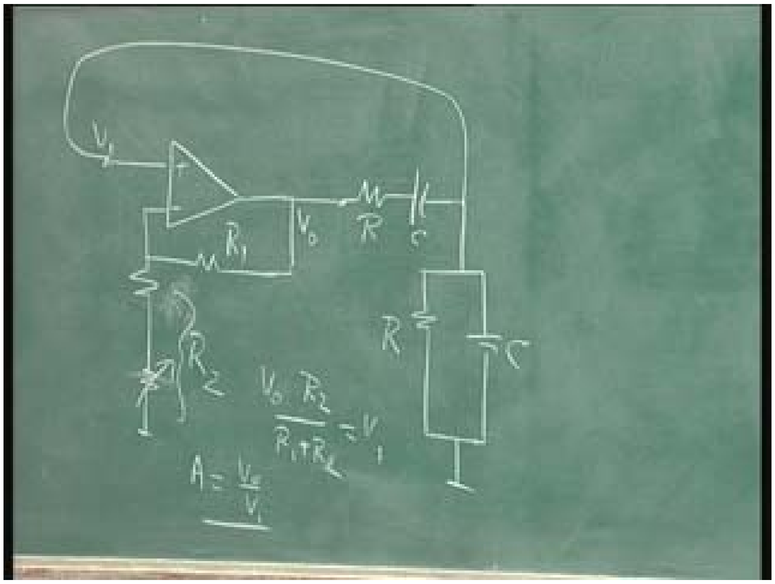

What you do put a variable resistor here and this whole thing as R_2 this resistance you adjust such that when this R_1 divide by R_2 is equal to 3 you get that amplitude. How do you do that? Take the output from here, what you do is (it is out of my syllabus).

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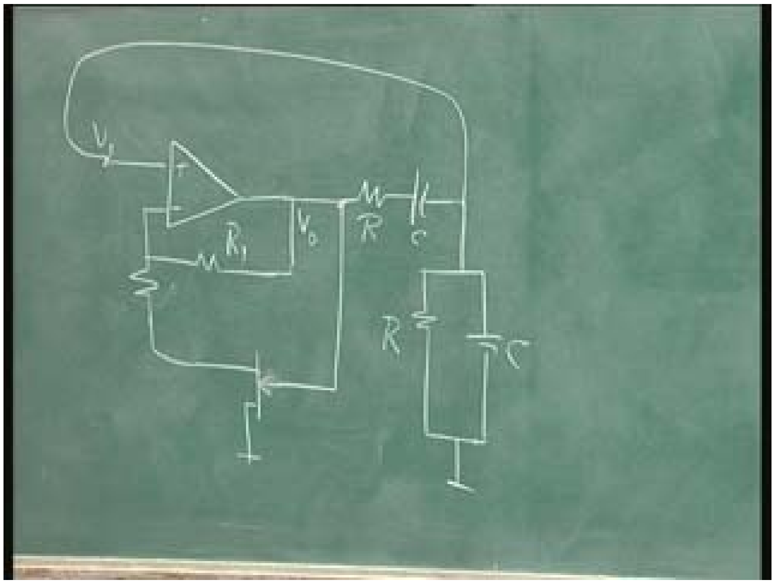

But, still what you do is you connect it to a simple arrangement to the JFET this is n channel the JFET this is the resistance. This resistance is variable resistance the resistance can be varied by varying the gate voltage depending upon the gate voltage you get this resistance. The output voltage whatever be the voltage, this will oscillate only when R_1 by R_2 is equal to 2. That is only when the total value becomes half of that if the output goes up what happens is V_{GS} goes up. You shift from one curve to another curve you can connect it such that it gets reversed biased or forward biased. You can get the output negative if you get it will be reverse biased. It can be a JFET or a MESFET. You can adjust the gate voltage see this will work as an oscillator only if this resistance is equal to R_1 by 2. That means only when this resistance has some particular value, supposing this is 2 k, this will be 1 k. If I put this as 1 k and this as half k only when this becomes half k it will work as oscillator. This will be half only when particular gate voltage and only for a particular output voltage.

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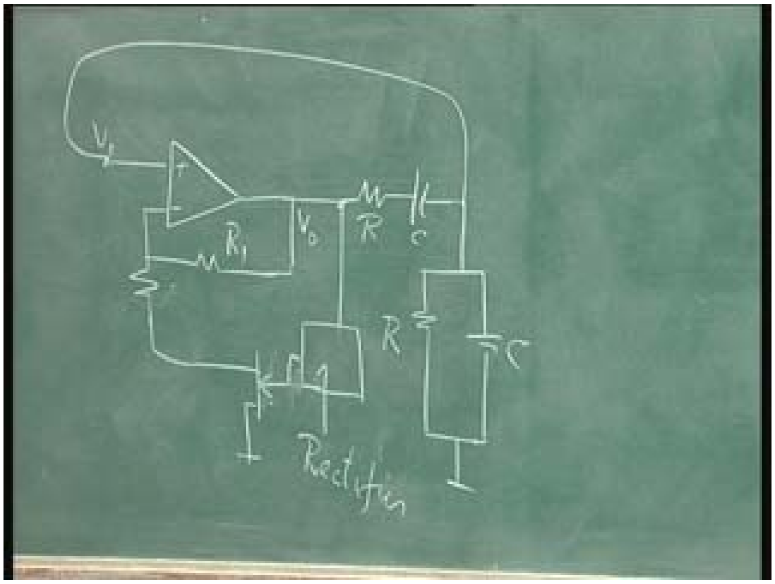

In fact, you must have a rectifier in between here. You need a rectifier here because, to give we will put to this gate you can get this should be DC what you get here is the AC. A rectifier can have an inverter if you like so that polarity is reversed and you can adjust that voltage. What is this voltage depends upon what the voltage is here is and only when it becomes 0.5 k for in this example that I have taken 2 k 1 k this should be half k let us say half k. When this becomes half k this becomes half k only for particular gate voltage that voltage decided by the output voltage. What happens is I am sure some of you must have done this experiments in laboratories, only for a particular voltage it has a gain of three output voltage that means actually it will work as an oscillator with a fixed amplitude. Amplitude is stabilized in Weinbridge oscillator

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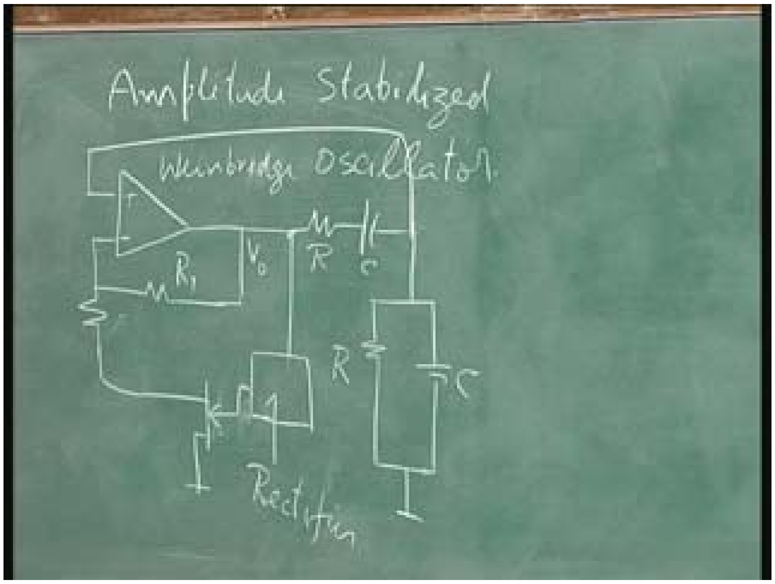

This is just of the discussion this is what you call it as amplitude stabilized Weinbridge oscillator. I thought it is better to see some of the applications are right away here; it is a very popular application. Whether you are an under graduate or using it some where it can be JFET it can be MESFET it can be even a MOSFET. Even MOSFET can be used because it has a linear region this is one application. There are several applications one can think of. Let us see what happens if I keep on increasing the V_{DS}.

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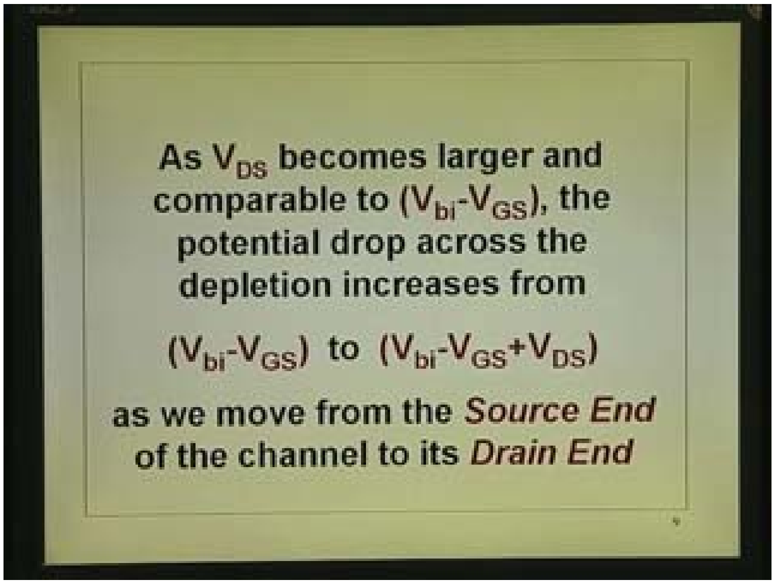

As V_{DS} becomes larger and comparable to $(V_{bi}-V_{GS})$, the potential drop across the depletion increases from

$(V_{bi}-V_{GS})$ to $(V_{bi}-V_{GS}+V_{DS})$

as we move from the *Source End* of the channel to its *Drain End*

As V_{DS} becomes larger what happens? Remember this particular analysis you have done I am going back to that, for the case V_{DS} is small compared V_{bi} minus V_{GS} please recall that. As V_{DS} is increased it will become comparable to V_{bi} minus V_{GS} it can even become larger. Let us see what happens. As V_{DS} becomes larger and comparable to V_{bi} minus V_{GS} the potential drop across the depletion layer increases from V_{bi} minus V_{GS} to V_{bi} minus V_{GS} plus V_{DS}. As we move from the source end of the channel to it is drain end.

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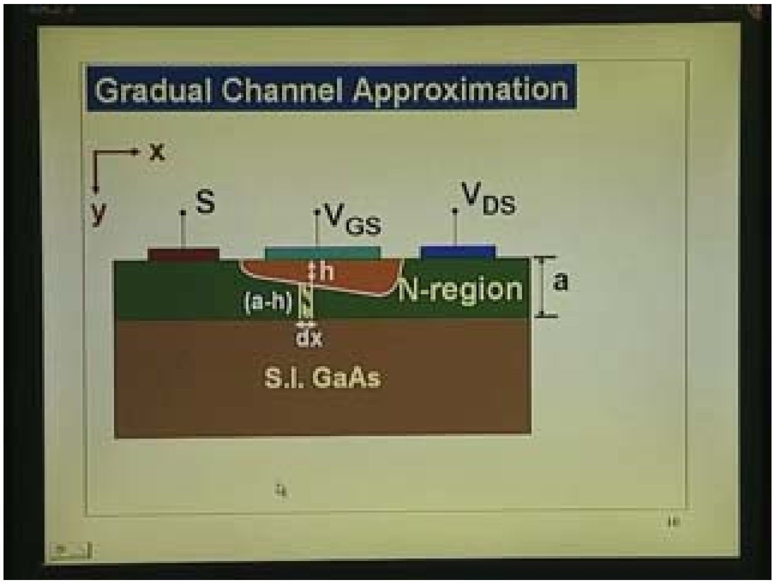

Gradual Channel Approximation

Let us see the meaning of that. At the source end, you cannot neglect this drop compared to the depletion layer voltage drop. In the linear region the drop from drain to source that is across this channel length is small compared to V_{bi} minus V_{GS} so V_{bi} minus V_{GS} is the drop here I have just put it here. If the drop in this direction is negligible what will happen to depletion layer width same if this drop is negligible the potential drop here and here will be same. Now, if the drop becomes comparable to that; this drop, as you move from this end to this end. The drop across the depletion layer becomes more and more it is understood. If you do not understand this is where some difficulty can be there.

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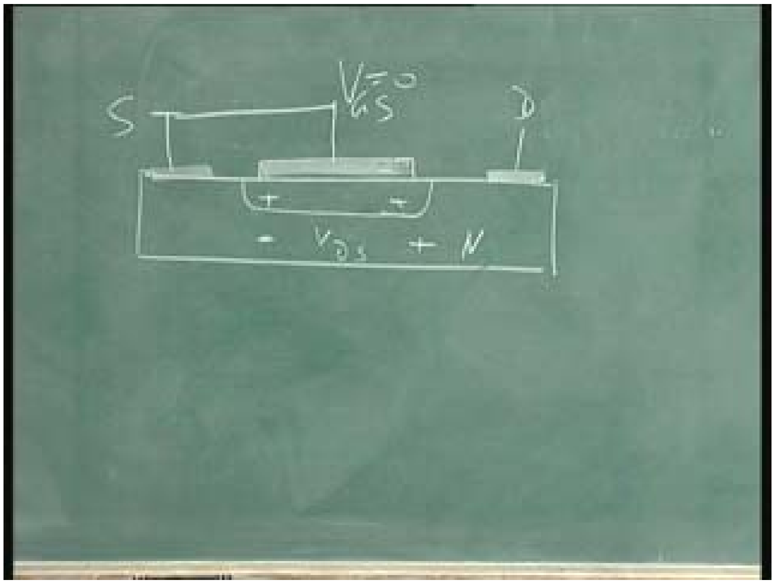

Take the case where it is easy to understand the situation where V_{GS} I do not even have to show the semi-insulating layer because it is only this layer which matters. This is drain and this is the source. Let us say V_{GS} is 0. If V_{DS} is small I have this depletion layer like this. This is the situation when V_{DS} is small that is drop in this direction negligible and what is the potential drop across this here now built-in potential from here to here there is no voltage V_{GS}. At this point it is V_{bi} and if this drop is negligible this also equal to V_{bi}. Now if there is a drop like this here V_{DS}, what is the potential here? I am neglecting this drop here. This is same potential here this is plus this is minus built-in potential. Built-in potential polarity is plus minus here plus minus here. Now, if I move from here to here, the potential from here to this point is what we are referencing. From here to that point in this region it is only V_{bi}. In this region it is actually equal to V_{bi} see this minus plus and this drop voltage here minus plus you have got additional drop coming up, this minus this region plus this adds on to that. You have got minus plus here you have got another minus plus coming up here, total potential drop from here is see you have one drop here another drop in this direction this drop adds on to that. You have got a voltage drop which is actually equal to V_{bi} plus V_{DS} here what happens is as a result of that (Refer Slide Time: 49:39) the depletion layer here becomes wider. Here it is V_{bi} if it is 0 here it is V_{bi} plus V_{DS} at any point here it is V_{bi} plus V of x. I have that point is clear enough it just adds on to the depletion layer potential across the depletion layer. It is addition just like clicking a pn junction applying extra voltage across that. See plus minus you are applying another plus minus across that plus minus. This is adding on to that plus minus plus minus. Let us say this as example. You take a pn junction into the barrier add on this potential if you reverse bias this, this is the potential, you connect this to that is as if we applied that voltage across that additional. Built-in potential plus V_{DS} comes in there.

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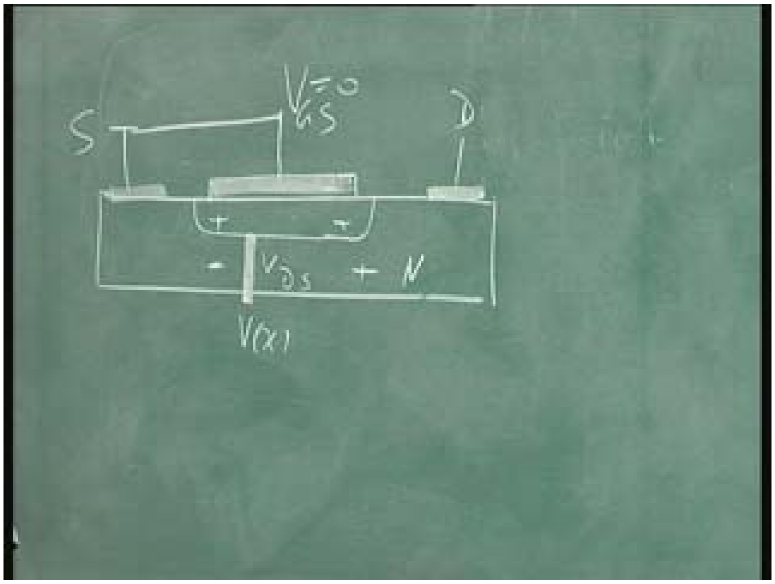

If you take any point here if this is V of x potential drop here is equal to V_{bi} plus V of x. In general if I apply V_{GS} to the gate this potential drop across the source region is equal to V_{bi} minus V_{GS}. At this point it is equal to V_{bi} minus V_{GS} plus V of x and at this point it is equal to V_{bi} minus V_{GS} plus V_{DS}. We are neglecting that one that is one simplification what Shockley did. What he did is total depletion approximation here that we have already made use of. What is the meaning of total depletion approximation or deep depletion approximation? Voltage is related to depletion layer charge by that equations square equation. The other thing is you can see that channel now gradually decreases and we can write the expression for depletion layer width here by subtracting total height a minus h. We can write h as equal to square root of twice epsilon_r epsilon_0 into the potential across that divided by q N_D.

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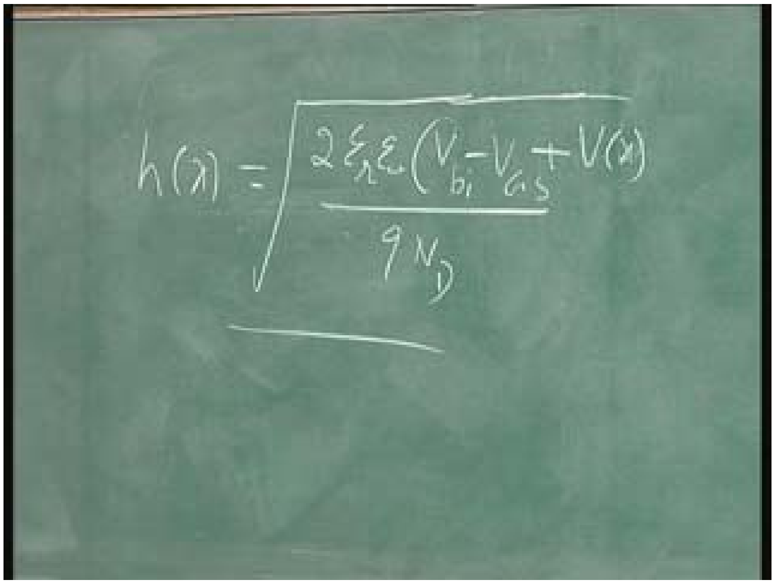

But you have to remember this see the h at any point can be written as square root of twice epsilon$_r$ epsilon$_0$ into whatever potential; we wrote this last time. But, now what you have got is plus V of x the drop that comes up divided by q N_D. Please remember if you write an expression of h the channel thickness is a minus h and current and voltages are related by V is equal to I into R, R is that thickness. That is all we are trying to find out again. Only difference is now is you have got (Refer Slide Time: 52:57) this channel thickness not constant right through but it is falling. Now, when we write this equation the meaning of that is the electric field in this direction is totally in this direction. If I call it as y and that is as x perpendicular to the channel is y parallel is x. What we assumed is even though there is a field in this direction because of the V_{DS} that field is negligible compared to the field in a y direction. That is the assumption that we make then only we can write this equation strictly because, electric field is completely one-dimensional in that direction that is called gradual channel approximation.

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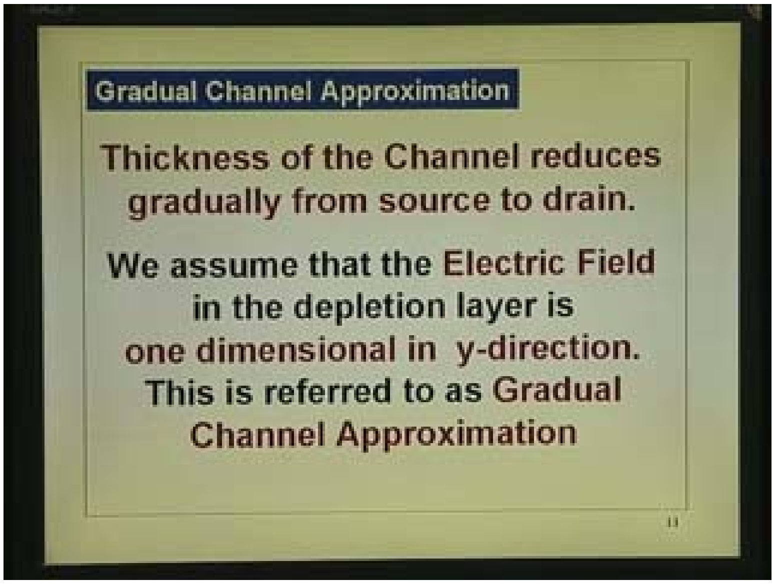

Gradual Channel Approximation

Thickness of the Channel reduces gradually from source to drain.

We assume that the Electric Field in the depletion layer is one dimensional in y-direction. This is referred to as Gradual Channel Approximation

The gradual channel approximation is famous jargon that is put up by all device physicists meaning the electric field is in x direction is negligible compared to y direction electric field. You can u use one-dimensional equations for writing the relation between depletion layer width and the potential across the depletion layer. Thickness of channel reduces gradually from source to drain we assume that electric field in the depletion layer is one-dimensional in a y direction. This is referred to as gradual channel approximation that was what Shockley did, a very clever thing at that time. If I started with two-dimensional layer analysis I think nobody would have understood JFET or MESFET that is the point.

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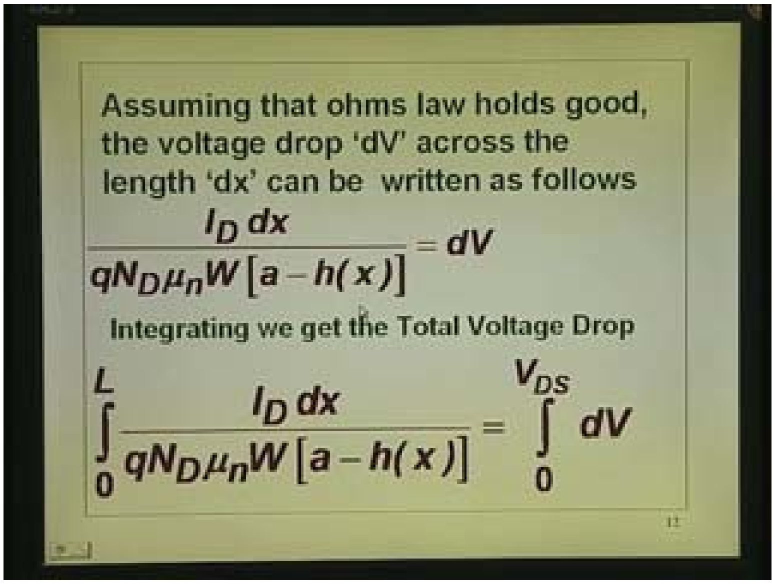

Assuming that ohms law holds good, the voltage drop ‘dV’ across the length ‘dx’ can be written as follows

$$\frac{I_D\,dx}{qN_D\mu_n W\left[a-h(x)\right]}=dV$$

Integrating we get the Total Voltage Drop

$$\int_0^L \frac{I_D\,dx}{qN_D\mu_n W\left[a-h(x)\right]}=\int_0^{V_{DS}} dV$$

Now, assuming that ohms law hold good the voltage drop dV across the length d of x can be written as follows: V is equal to I into R delta V is equal to I_D into resistance of the thickness. What we are writing now (Refer Slide Time: 55:09) is the resistance of that region and drop in that region dV is I_D into the resistance of that region. I_D is constant right through because, after all what current flows through there will come out here, it is continuous I_D into R. What we do is dV the voltage drop across that region thickness is given by I_D into R of that d of x length that is given as d of x divided by this quantity that is actually 1 by q N_D mu_n is rho Id into rho d of x divide by area of cross section. Area of cross section now is actually W into channel thickness; channel thickness is a minus h that is potential dependent. We use this integrating we get the total voltage drop. All that we do is integrate that we substitute for h here. That term h is given by this term it is a voltage dependent term. I will continue on this in my next lecture. When we integrate it what sort of terms we get. Today, we have seen that, we get the linear characteristics. But, we will see now that it will deviate from linearity if we include the drop in the y direction. If you include the V_{DS} or V of x that part we will discuss in our next lecture taking this completing the integral into account.